CHAPTER 2

ENGINEERING GEOLOGY

2.1 INTRODUCTION

The geologist uses a variety of tools to study the earth, perhaps to depths of hundreds of meters, to gain information on a variety of matters, such as the occurrence of petroleum products, the prediction of earthquakes, and the science of the earth. While these matters are of general interest, the engineering geologist has a particular interest in near-surface geology, principally to guide the subsurface investigation and planning for construction.

The work of the engineering geologist is crucial in the design and construction of dams and major earthworks and is somewhat less important in the design of foundations. The design of the subsurface investigation for a project begins with a study of the geologic process that resulted in the creation of the soil and rock at the site. The investigation continues, with near-surface geology playing an important role as the final design of the foundation is made and the completed foundation is observed.

An interesting fact is that the late Dr. Karl Terzaghi, the father of modern geotechnical engineering, began his studies of soil with a study of geology and maintained an intense interest in geology throughout his career. An early paper (Terzaghi, 1913) dealt with karst geology and a later one with the limitations of subsurface investigations in revealing all information of significance (Terzaghi, 1929). In a paper about Terzaghi's method of working, Bjerrum (1960) wrote: "The intimate knowledge of the geology of the whole area is as necessary for his work as the subsoil exploration which follows." There is good reason to believe that Terzaghi's method of working remains a valid guideline.

Presented here are brief discussions of geologic processes that affect the character of near-surface soils, availability of information on geology to the engineer, an example of the geology of a selected area, and geologic features that affect subsurface investigations and designs.

2.2 NATURE OF SOIL AFFECTED BY GEOLOGIC PROCESSES

The information presented here provides only a brief treatment of some aspects of geology that affect the techniques of subsurface investigation and the design of some foundations. The following sections are intended principally to promote the investment in an adequate effort to develop knowledge about the geology of a site prior to planning the subsurface studies and the subsequent design of the foundations.

2.2.1 Nature of Transported Soil

Transported by Water Almost any flowing water will transport particles of soil. The particles originate as rain hits the earth and are deposited when the velocity of flow is reduced or when particles of soil form flocs that settle. Boulders are pushed along in mountainous areas where stream beds are steep and the velocity of the water is very high. The power of flowing water can be illustrated by Figure 2.1, which shows the erosion of limestone along a

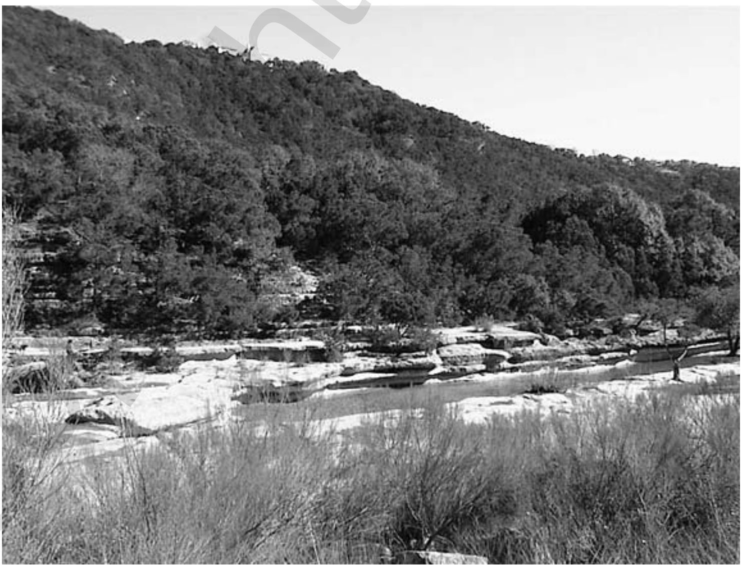

Figure 2.1 Erosion of limestone along a stream in Texas.

stream in Texas. At the other end of the scale, rivers transport particles of clay into bodies of water, lakes or the sea, where flocculation occurs and the flocs gain enough weight to fall to the lake bed or sea floor.

Thick beds of clay, with some particles of silt size, can be found on the ocean floor at many locations. An example is at the mouth of the Mississippi River. Year after year, thin layers of clay are deposited as floods along the river erode particles of soil. The weight of the soil above a particular depth causes drainage or consolidation of the clay at that depth. If deposition has ceased at a particular location, the clay will reach a state of equilibrium after a period of time with no outward flow of interstitial water, and the stratum of clay will become normally consolidated. The shear strength of the clay will be virtually zero at the surface and will increase almost linearly with depth.

If deposition continues, the underlying clay is underconsolidated, with drainage continuing. Careful sampling and testing of the clay will reveal its nature, and the engineer will consider the detailed character of the stratum of clay in designs.

Particles of sand and gravel are carried along by flowing water and are deposited with a drop in the velocity of the water. Such deposits occur near the beds of streams that exist now or did so in the past. Such deposits are usually quite variable because of the erratic nature of stream flow. The relative density of such deposits also varies significantly, depending on their historical nature. Fine sand and silt are deposited in bodies of water as the velocity of a stream in flood pushes the suspension into a lake or ocean. Deposits of sand and silt can be found in the deltas of rivers, such as near the mouth of the Mississippi, and sometimes contain decayed vegetation.

Nature creates complex patterns, and the near-surface geology rarely can be known with absolute certainty. Stream flow in the past, when the ground surface was uplifted, incised valleys that, after submergence, became filled with soft sediments. Such examples exist in the Gulf of Mexico near the coast of Texas. Offshore borings may reveal a regular pattern of soil, but such a geologic event may result in an unpleasant surprise to builders of pile-supported structures.

Transported by Wind Over geologic history, wind has played an important role in creating soil. In the deserts in some parts of the world, sand is prominent in the form of dunes, and the dunes may be in continuous motion. Rainfall is small to nonexistent, and construction is limited. If construction is necessary, the engineer faces the problem of stabilizing the wind-blown sand. Other wind-blown soil is more amenable to construction.

Dust storms in the Midwest of the United States in the first half of the 20th century transported huge quantities of fine-grained soil. Over long periods of time, deposits of great thickness were laid down. Such a soil is loess, found in the United States, in Eastern Europe, and in other places. Vegetation

grew during deposition, and deposits of considerable thickness of vertically reinforced soils were developed. Loess will stand almost vertically when deep cuts are made.

If a sample of loess is placed under load in a laboratory device and water is added, the sample will undergo a significant reduction in thickness or will "collapse." Loess is termed a *collapsible* soil. Drainage is a primary concern if shallow foundations are employed. Deep foundations will normally penetrate the stratum of loess.

2.2.2 Weathering and Residual Soil

Residual soils are derived from the in-place weathering of rocks and are found on every continent, including the subcontinents of Australia and Greenland (Sowers, 1963). Residual soils exist in southeastern North America, Central America, the islands of the Caribbean, South America, southern Asia, and Africa. The soils occur in humid, warm regions that promote rapid decomposition of the parent rock.

There are many processes of weathering, depending on the climate during the geologic time at the site. The processes can be differential expansion and contraction, freezing and thawing, chemical action, rainfall and leaching, and the action of organisms.

As is to be expected, the decomposition is not uniform, with residual soil varying in thickness. At certain places in India, some areas of the parent rock resisted decomposition and were left in residual soil as boulders. Residual soil can sometimes be expansive, such as the soil shown in Figure 2.2. The site had been excavated, and drying of the clay generated the pattern of cracks shown in the foreground. The structure and physical characteristics of residual soil are related to those of the parent rock, but careful sampling and testing can obtain properties for use in design. In situ tests are frequently very useful.

Deposits of organic material can weather into peat, muck, and muskeg and can pose severe problems for the engineer.

Weathering of soils such as limestone has resulted in *karst* geology where caverns and openings in the rock are prevalent. Karst geology exists in many areas of the world and was studied by Terzaghi early in his career (1913) (see Section 2.2.5).

2.2.3 Nature of Soil Affected by Volcanic Processes

Much of the soil and rock thrown out and up by ancient volcanoes has been weathered and causes the normal problems in determining properties for design and construction of foundations. An interesting artifact from the ancient volcanoes that surround the Valley of Mexico is that lakes in the Valley were filled to a considerable depth with volcanic dust thrown up over long periods of time. The resulting soil has extremely high water contents and void ratios. Dr. Leonardo Zeevaert (1975) described to one of the authors an experience

Figure 2.2 Desiccation cracking in expansive clay.

early in his professional life when he sent data on the results of laboratory testing to his professor in the United States and got the following reply: ‘‘Son, you have misplaced the decimal point.’’

Zeevaert (1972) has written extensively on the design of foundations in the Valley of Mexico and elsewhere, particularly with respect to designing to accommodate the effects of earthquakes.

2.2.4 Nature of Glaciated Soil

Glaciers transport rock and other materials that are embedded in the ice or are picked up from the surfaces of rock as the glacier moves. The material carried along by a glacier is termed *drift.* Glacial deposits are of two general types: *moraines* or *till* and *outwash.*

Till is deposited directly by the glacial ice and is characterized by a wide range of particle sizes. Stones and boulders can exhibit scratches or striations due to being carried along by the ice. Moraines occur when a glacier dumps a large amount of irregular material at the edge of the ice sheet that is deposited as the glacier retreats. A large amount of material may be dumped in an area if the glacier stalls in its retreat

The outwash from melt water is mainly fine-grained material that forms a plain or apron. The material is usually stratified and may exist as long, winding ridges. Many glacial deposits create a problem for the foundation engineer because of their lack of homogeneity. A particular problem for deep foundations occurs when a glacier leaves a deposit of boulders. Not only will the

deposit be difficult or impossible to map, but penetrating the boulders with piles can be extraordinarily difficult.

Varved clay occurs with seasonal deposition into lakes, but such soil is most often associated with glaciation. Each layer or varve contains a wide range of grain sizes, with gradation from coarsest at the bottom of the layer to finest at the top. Walker and Irwin (1954) write that a lake was formed when the Columbia River was dammed by ice during the last Glacial Era and that seasonal deposition occurred in the lake for hundreds of years, resulting in the Nespelem Formation found chiefly in the valley of the Columbia River and along its tributaries. While perhaps not typical of varved clay found elsewhere, the varved clay along the Columbia yielded greatly varying results in field and laboratory tests, lost strength due to even minor disturbance, was unsuitable for foundations, and was susceptible to sliding.

2.2.5 Karst Geology

The processes of solution of limestone and dolomite result in openings and cavities, some of which are extensive and important. The Edwards Limestone in Central Texas is an aquifer that provides water for many of the communities and businesses in the area. During construction of a highway, a drill exposed a cavity and alerted the highway engineers to make careful investigations for bridges in the limestone area. Several caves have been opened in Central Texas as attractions for tourists.

Some of the openings collapsed in the past and are filled with boulders, clay, or surficial soils. The weathering processes are continuing in some areas, with the result that in sections of Florida sinkholes appear suddenly, some of which may be quite large. Investigation of the subsurface conditions in karst areas is especially critical in foundation design. In addition to careful borings of the limestone or dolomite, ground-penetrating radar is sometimes appropriate.

A view of a section of limestone in an area of karst geology excavated for a roadway is shown in Figure 2.3. The cracks and joints in the limestone are evident. Rainwater can penetrate the openings, some of the limestone goes into solution, and a cavity, sometimes quite large, will develop over perhaps centuries.

2.3 AVAILABLE DATA ON REGIONS IN THE UNITED STATES

Rich sources of information have been provided by engineers and geologists working in local regions in the United States. The engineer making plans for foundations at a particular location may wish to take advantage of these studies of local areas. Some examples are given to illustrate the availability of such information. Fisk (1956) wrote about the near-surface sediments of the continental shelf off the coast of Louisiana. Included with the paper are col-

Figure 2.3 Bedding planes, cracks, and joints in sedimentary limestone.

ored drawings of various regions at present and in earlier geologic eras. The paper could be of considerable value to engineers making designs for the areas treated in the paper.

Otto (1963) wrote on the geology of the Chicago area. May and Thompson (1978) described the geology and geotechnical properties of till and related deposits in the Edmonton, Alberta, area. Trask and Rolston (1951) reported on the engineering geology of the San Francisco Bay of California.

2.4 U.S. GEOLOGICAL SURVEY AND STATE AGENCIES

The U.S. Geological Survey (USGS) maintains a vast amount of geologic information developed in the past and is adding to their collections. Geologic and topographic maps are available for many areas of the United States. The USGS released a study (1953) consisting of six maps entitled *Interpreting Geologic Maps for Engineering Purposes Hollidaysburg Quadrangle, Pennsylvania.* The maps were prepared by members of the Engineering Geology and Ground Water Branches. The first two maps in the release were a topographic map and a general-purpose geologic map. The final four maps were interpreted from the first two and showed (1) foundation and excavation conditions; (2) construction materials; (3) the water supply, both surface and underground; and (4) site selection for engineering works. The text accompanying the set stated: ‘‘This set of maps has been prepared to show the kinds of information, useful to engineers, that can be derived from ordinary geologic

maps.'' The text and the detailed information on the right side of each map provide an excellent guide to the engineer who wishes to study an area with respect to the design and construction of foundations for a particular project.

Aerial photographs are available from the USGS and can be used to gain information on the occurrence of different types of soil (Johnson, 1951; Stevens 1951) as well as the geology of an area (Browning, 1951). The Iowa Engineering Experiment Station (1959) has published a number of aerial photographs to illustrate their use in identifying geologic conditions such as areas of sand covered by variable amounts of flood-deposited clay near the Mississippi River; erosion of shale to create a dendritic stream pattern; sinks identifying an area of limestone; almost horizontal lava flows that are cut by streams; granite or similar rock revealed by a fine fracture pattern; stable sand dunes; and alluvial fans extending out from mountains.

The current *National Atlas* is available online (http://www.nationalatlas.gov), and maps are available under various headings, including, for example, construction materials, coal fields, geologic maps, and seismic hazards. GEODE (Geo-Data Explorer) is an interactive world map (http://geode.usgs.gov) that allows the user to retrieve, display, and manipulate multiple types of information, such as satellite images, geologic maps, and other information.

Many states have an agency that provides information on the geology of the state. In Texas, the Bureau of Economic Geology has a number of publications of value to engineers—for example, a report on the engineering properties of land-resource units in the Corpus Christi area. In addition, local groups may be able to provide useful information that will assist the engineer in planning a site study.

In view of the extensive information available from governmental agencies and the importance of such information to the design of foundations, the engineer may wish to take the time to gather appropriate information for a specific project.

2.5 EXAMPLES OF THE APPLICATION OF ENGINEERING GEOLOGY

In 1997 the European Regional Technical Committee 3 ''Piles,'' a group of the International Society for Soil Mechanics and Foundation Engineering, sponsored a conference in Brussels to present European practice in the design of axially loaded piles. Papers were submitted by engineers from a number of countries. Of special interest is that most of the articles began with a section on the geology of their country: Belgium (Holeyman et al.); the Czech Republic (Feda et al.); Denmark (Skov); Estonia (Mets); Finland (Heinonen et al.); France (Bustamante and Frank); Germany (Katzenbach and Moormann); Ireland (Lehane); Italy (Mandolini); the Netherlands (Everts and Luger); Norway (Schram Simonset and Athanasiu); Poland (Gwizdala); Romania (Manoliu); Sweden (Svensson et al.); Switzerland (Bucher); and the United Kingdom (Findlay et al.). Useful information, even if abbreviated, was pre-

sented about the geology of the various countries. The articles illustrate the importance of considering geology when designing foundations.

The late D. C. Greer, State Highway Engineer of Texas, renowned for his record of constructing highways in a big state, mailed all of the district engineers a map of the geology of Texas in August of 1946, where the presence of Taylor Marl was indicated. An accompanying document presented data on the poor behavior of asphaltic and concrete pavements on Taylor Marl and identified the material as an expansive clay. A later report in September of 1946 dealt with the performance of highways on other geologic formations and identified areas of Eagle Ford Shale and Austin Chalk. Mr. Greer urged state engineers to submit data on the performance of highways and cut slopes with respect to the local geology to allow such information to be disseminated for the benefit of engineers making highway designs.

The Nelson Mandela Bridge in Johannesburg, South Africa (Brown, 2003), was built across the city's main rail yard of 42 tracks. The design of the foundations was complicated by the existence of a graben at a depth of 50 m near the center of the bridge. The highly weathered material filling the graben was unsuitable for supporting a foundation, so the bridge was designed with two pylons with foundations at the edges of the graben.

2.6 SITE VISIT

The value of a visit to the site of a new project is difficult to overestimate. Many observations can lead to valuable insights into the problems to be encountered in the forthcoming construction. Among the things that can provide information on the site are the kinds of structures on the site and their foundations, if discernible; any observable deleterious movements of buildings in the area; the kinds of soil observed in excavations or in the sides or beds of streams; cracks in soil and desiccated soil; the quality of pavements in the area; and comments from homeowners and occupants of buildings if available.

A telling example of information to be gained occurred in 1953 when Professor Parker Trask took his graduate class in engineering geology on a tour of East Bay in California. Trask pointed to rolling hills where evidence of minor slides was apparent. Many minor scarps and slumps were observed, showing that the soil on a slope had a factor of safety close to unity. Newspaper reports during the period following the tour noted that slides had occurred when cuts were made for the construction of various projects. The resulting steep slopes reduced the safety against sliding.

PROBLEMS

P2.1. Make a field trip through an area assigned by your instructor and write a report giving all of the information that can be gleaned about the geology of the area.

P2.2. Use the USGS website and make a list of the information that could help an engineer understand the geology of a site assigned by your instructor.

P2.3. Term project. The class will be divided into groups of three to five students, and each group will be assigned an area of study where foundations are to be installed for a 10-story building with a plan view of 60 by 80 feet. Obtain relevant documents from the USGS and from local sources, and write a report presenting all pertinent information about the geology of the site.